An International System of Physical Units and the Teaching of Such Units to American Students

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THIS paper is a plea for the exclusive use of the metric system in the teaching of all grades of physics, both basic and applied, throughout North America. In South America no such plea is needed.

It is generally agreed that in American secondary schools, colleges and universities, the advanced principles of basic physical sciences, such as light, heat, electricity and magnetism, are nearly always taught and studied in relation to units of metric measure. Consequently, no criticism is here offered against such teaching or study of advanced and basic physics. There are, however, other physical sciences, such as mechanics, acoustics and astronomy, which are often taught and studied in relation to nonmetric units, especially in their elementary stages, and in their applications to practice. It is here claimed that such nonmetric units lower the level of instruction by obscuring, complicating and confusing the subject. It is submitted that by adhering closely to metric units, the study of all physics is clarified, simplified, rendered more scientific and maintained on an international basis. It is also desirable to standardize internationally upon a single system of metric physical units.

Metric Measures

In order to be specific, we may, for the purposes of present discussion, define the metric system as the decimal system of weights and measures (international in the sense of being in general use among many nations) that is based upon the international standard meter and standard kilogram, as preserved and maintained by the International Bureau of Weights and Measures at Sèvres. The metric system includes such decimal variants as the c.g.s., or *centimeter-gram-second*, system of units, and the *volt-ohm-ampere* series of practical electrical units, as adopted by various international scientific assemblies during the last fifty years. On the other hand, nonmetric measures may be defined as local national measures or systems of measures that are ordinarily nondecimal in their mutual relations. In practice, there are only two nonmetric systems of weights and measures of any importance as regards the study of physics; namely, the British system and the American system. These are by no means identical, but have much in common.

Single-Unit Character of a Decimal Series

It may be claimed, and is generally admitted, that any decimal series of units, such as the American and Canadian decimal currency units —*dollar*, *dime*, *cent* and *mill*—are not four different units, but present a single unit—the *dollar*—and three subdecimal parts of the same. These may be properly regarded as the *decime* of the dollar, the *cent* of the dollar and the *mill* of the dollar, respectively. In the same way, the series of metric lengths—*kilometer*, *hectometer*, *decameter*, *meter*, *decimeter*, *centimeter*, and *millimeter*—do not connote seven different units, but one unit—the *meter*—and six decimal multiples or submultiples of the same. The unabridged statement of the list would be *one thousand meters*, *one hundred meters*, *ten meters*, *one meter*, *one-tenth meter*, etc.

In contrast to the single-unit character of a decimal series, stands the multiple-unit character of any nondecimal series of units. Thus, the American arithmetical table of Long Measure contains the following nondecimal units: *inch*, *surveyor's link*, *foot*, *yard*, *fathom*, *pole*, *surveyor's chain*, *furlong*, *statute mile*, and *nautical mile*. Although only four of these, the *inch*, *foot*, *yard* and *mile*, are in ordinary everyday use, yet

even these four make a relatively complex system that is difficult for non-English speaking people to understand, and all ten have usually to be memorized at school. British arithmetical tables of Long Measure commonly add to the preceding list the *hand* and the *league*. Such tables occasionally also add the *barleycorn*, *palm*, *span* and *bolt* (of cloth).

The result of all these nondecimal Anglo-American units is that, whereas in the metric system there are only three[1] units—the *meter*, *liter* and *gram*, in the American system there are some fifty units, and in the British system there are some sixty. In the arithmetic books of the numerous metric countries, there are either no tables of weights and measures, or else a single table of the kilo-to-milli prefixes. In the arithmetic books of the English-speaking peoples, there are some nine or ten tables to be learned at school. Moreover, between the fifty-odd American units and the sixty-odd British units, there are thirteen having the same name, but differing in magnitude, either between the different tables, or between corresponding tables of Great Britain and America. These ambiguous units are the *drachm*, *scruple*, *ounce*, *pound*, *hundredweight*, *ton*, *peck*, *bushel*, *gill*, *pint*, *quart*, *gallon* and *barrel*. The most serious offenders in ambiguity are probably the *gill*, *pint*, *quart* and *gallon* of liquid measure. In the British Empire, these are severally over twenty percent larger than in the United States: for instance, on the south shore of Lake Erie, a *liquid quart* is 0.94636 liter, but on the north shore, or Canadian side, it is 1.1365 liters.

So manifest is the contrast between the simplicity and precision of the metric system and the ambiguity of nonmetric systems for the teaching of physics, that physics teachers would probably have decided to teach all branches of physics exclusively in the metric system, if certain objections to the more extended use of the metric system had not been current among them. We may briefly examine these objections, so far as the writer has been able to locate them.

(a) *That the metric system should be discouraged, because it is a decimal system, and that a duodecimal system, admitting of more numerous numerical factors (2, 3, 4 and 6, as against only 2 and 5) would be better.* To this it may be replied that, although theoretically 12 has advantages over 10 as an arithmetical base, yet all the world uses the base 10 and decimal arithmetic; nor is there any hope of world-wide arithmetical reform in this respect. Moreover, in the absence of experience with duodecimal arithmetic, it is uncertain whether the advantage of increased factoring would outweigh the disadvantage of a more complicated arithmetic. For instance, we should have to learn and remember that the numerical expressions 10, 100, 1000, etc., which now denote the numbers ten, one hundred and one thousand, would, on the duodecimal base, mean and represent what we now write as 12, 144 and 1728.

(b) *That the meter is not a precise decimal fraction of our earth's quadrant but is an arbitrary unit of length.* There can be no question that the meter was not selected arbitrarily, in the sense of a random choice. It was selected to be, as nearly as could be measured, the ten-millionth part of the earth's northern quadrant through Paris. Geodetic measurements were made over that portion of the meridian which lies between Dunkirk, in France, and Barcelona, in Spain, during the period 1791 to 1799. It was agreed by an international committee that the standard meter thus derived should not be considered as subject to amendment or modification in the light of subsequent and probably more precise redeterminations. The most recent measures are stated to indicate that the standard meter is shorter than the theoretical ten-millionth of a quadrant by one part[2] in five thousand. In other words, the standard meter is approximately 0.2 mm too short. With reference to modern geodetic precision, this would be a considerable error; but at the date of executing the original meter bar, near the end of the eighteenth century, it would be regarded as a small error. For purposes of computation, the correction of 1.000229 is readily applied; but for practical chart work, the discrepancy is trivial at the present time. A large map, say one meter square, accurately engraved, would be 0.2 mm short in length and breadth, considered as a decimal representation of a small area on the earth; but casual changes in its dimensions with climatic variations of temperature and moisture would probably be considerably greater than this error in the scale.

(c) *That the kilogram does not strictly represent the mass of a cubic decimeter of pure water under standard specifications; and that hence the metric system is invalidated.* An

[1] The question is sometimes raised whether the *nautical mile*, as an international unit of length at sea, does not introduce an extra and a non-decimal unit of length into the metric system. An answer is that in the complete metric system, angles are decimal and not sexagesimal, commencing with the quadrant of 100 *grads*, each subdecimalized. On that basis, the decimal minute or *centrigrad* of arc is the 1/10,000 of the quadrant, or 1 km, whereas the duodecimal minute of arc, being 1/5400 quadrant, is 1.853 km, approximately the length of the *nautical mile*. Decimal angles are used to some extent in France, as well as transits and theodolites with 400 grads to the circle.

[2] *Annuaire pour l'an 1932*, Bureau de Longitudes, Paris, p. 145.

answer to this objection is that the kilogram standard was constructed to have the mass of a cubic decimeter of pure water at the temperature of 4°C and the pressure of 760 mm of mercury. More recent measurements[3] are stated to indicate that the standard kilogram represents 1.000027 dm,[3] under those specifications, or its water volume is in excess by about 27 parts per million. It is generally admitted that the discrepancy is remarkably small, in view of the date of the measurement. For all ordinary scientific volumetric purposes, the error may be neglected; but the correction factor can, when necessary, be applied. Moreover, without altering the mass of the standard kilogram, the error could be eliminated, if it were so internationally desired, by altering the specification of the pressure. If the kilogram of water were subjected to a pressure of about 1.5 atmospheres, it would occupy the specified cubic decimeter of volume.

(d) *That the metric system is unsuitable for practical use in English-speaking countries.* An answer to this charge is contained in the science, art, industry and business of spectacle-lens production. Until about the end of the last century, spectacle lenses in America were prescribed, ground, polished, adjusted and sold in the customary inch system of measures. In more recent years, all these operations have been, and now are, regularly carried out in the metric system. The oculist or optometrist measures the lenticular needs of the eye in *diopters*, and prescribes the glasses required in these metric terms. The optician grinds and polishes the glasses accordingly, measuring, fitting and adjusting them to metric measure. This is not only a simpler procedure to follow but it is also international, and prescriptions made in one country can now ordinarily be worked out in any other. The change in this industry from nonmetric to metric units was effected without governmental edict or control and entirely by conventional agreement.

(e) *That the general introduction of the metric system into America must be impracticable, because of the consequent necessity of discarding a large part of the existing installed machinery.* To this it may be answered that the metric system is an improved means of measuring, specifying and computing dimensions, and not necessarily a standard for manufacturing. In no country is it compulsory to use metric gauges, drawings or tools in factories. It is only compulsory to buy and sell by the meter and gram. Inspectors visit stores and markets, not factories or assembling plants. Purchase and sale of goods are matters of public and even of international interest, whereas manufacture is a matter of private concern. If America adopted the metric system officially, it is only reasonable to suppose that the goods that are made today would continue to be made from the same drawings and with the same tools, but that the sales would be made according to revised catalogs with prices based on the meter and gram. There would be public inconvenience at the outset in learning the new catalogs and prices but the change should not materially affect the factories, at least until the old drawings and tools had worn out and had to be replaced. Moreover, the experiences of a number of European countries that have changed to the metric system during the last half century do not indicate serious expenses due to discarding of machinery. Japan, for example, is now in process of changing over to the metric system, and the writer, during a recent visit, was unable to discover complaints owing to discarding of original machinery, mostly built in English-speaking countries. It is also well-known that American standard tools have for many years been exported to metric countries, which does not suggest their incapacity for use in production for sales in meters and grams. Many such American tools can be seen abroad today in metric countries.

[3] *Smithsonian Physical Tables*, 6th edition, p. 6.

Steady Infiltration of the Metric System into America

It is believed that a careful examination of the present and recent status of measures in America will show that this country is in steady process of transition to the eventual complete adoption of the metric system, although it is not possible to predict the final official date of acceptance. In the Anglo-Saxon countries such reforms have usually been very gradual. It is reported in Ball's *History of Mathematics* that the process of complete adoption of the Arabic system of numerals in the business world, after that system had been accepted by the scientific world, occupied, in England, about 150 years. During that time, merchants' accounts were kept in the system of Roman numerals. The change was slowly effected in the face of strong opposition. At the present date there are vestiges of the Roman system of numerals on the faces of clocks, on the bindings of books and in the dates engraved on public buildings. Again, the transition from the Julian to the Gregorian calendar, which was made in nearly all western continental Europe in 1582, was not effected in Great Britain and America until 1752. Taking the start of the metric system, in France, as 1800, and estimating according to the incubation period of Arabic numeral reform, we might hazard the date of metric reform with us as, say, 1950; whereas, according to experience in calendar reform, it might be 1970. In any case, however, such reforms advance very slowly in democratic countries, which is perhaps a wholesome safeguard against hastily unwise action.

Meanwhile, the use of the *meter* and *gram* goes slowly but steadily forward among us. Electric energy is bought and sold exclusively

in *kilowatt-hours*, and the *kilowatt* is a metric unit of power. All of the international practical units—*volt*, *ohm*, *ampere*, *farad*, *coulomb* and *henry*—are metric units. Some of these are firmly rooted in common speech. Radio-broadcasting has made us familiar with *meter wave-lengths*. Moving-picture photographic films are sold here on a millimeter-width basis. Each five-cent nickel coin, when fresh from the mint, weighs 5 g, and subsidiary silver coin (50-cent, 25-cent, and 10-cent pieces), weigh at the rate of 25 g to the dollar. On the other hand, our bronze coins still remain nonmetric; each cent piece, or "penny," weighs 2 dwt, or 48 grains troy (3.11 g).

Within recent months, the Amateur Athletic Union has announced its decision to use metric measures exclusively in all official American track and field events.[4] A.A.U. swimming distances are still nonmetric, apparently because indoor swimming tanks are constructed, at present, to conform with one hundred yards as the standard of distance. Perhaps such tanks will be built in the future with the slight extra length needed to fit metric records. Otherwise, American swimmers will be prevented from qualifying for world records except during Olympic races, once every four years.

If, then, North America is actually in process of slow transition to the metric system for general use, as seems reasonable from the foregoing considerations, it is all the more appropriate that the subject of physics should be taught entirely in metric terms. Nevertheless, in giving out daily problems for quantitative solution, it is reasonable that at least a certain part of them should be formulated in nonmetric customary units, both as to questions and answers, in order to familiarize the students with mental transition from one system to the other and to avoid the danger of an academic insulation of the subject. According to the writer's experience, it is ordinarily much easier and swifter to solve such vernacular problems in three steps: (a) recast the problem into metric terms, (b) compute the solution, and (c) recast the metric solution back into vernacular terms. The quantitative language of modern science is essentially metric, and it is psychologically economical to conduct trains of physical thought in physical language. But physicists have to be ready to solve a practical problem at any time from vernacular data, without reference to conversion tables. This familiarity with both unscientific and scientific units will probably continue to be necessary with physicists, diminishingly, for years after the advent of the metric system into general national affairs.

In reading scientific papers and communications published in physical journals, it is astonishing to see the incongruous association of units frequently employed by some of our leading physicists. On the same page, and sometimes in the same sentence, there will be both scientific and unscientific units, both metric and nonmetric. This incongruity is not surprising when we remember that in different parts of a scientific presentation, the physicist will be likely to draw alternately on his scientific memory for metric details, and upon his vernacular memory for subsidiary elements. When these passages are perused, say one hundred years hence, by the generation of American physicists of that day, it is quite likely that the association of scientific and unscientific units will sound quaint and archaic. Effort should be made to use scientific units in all our scientific work, if only for the sake of consistency. Many physicists defend themselves in such practices by claiming that if they used metric units throughout their discourses, their audiences would not understand or follow them. The metricists retort, however, that this is but a cloak for laziness in thought and expression; all hearers of sufficient intelligence to follow even an elementary scientific disquisition, must already know the elements of the metric system, and therefore can understand the statements more readily in terms of the simple *meter* and *gram* than in terms of the multiple-unit tables of our inheritance. A careful inspection of current American literature of today, as compared with corresponding literature of, say, forty years ago, will probably convince an unprejudiced enquirer that the use of metric terms as accepted vehicles of expression is much more general than formerly. Forty years ago, if a writer referred to "a kilometer," he would

[4] *The Metric System in Track and Field Events*, Sci. Mo. **36**, 385–386 (1933).

be likely to follow it with a parenthetical explanation, such as (0.621376 mile), to, say, six-digit precision, when the original quotation may have been left indefinite to perhaps ten or even twenty percent. Nowadays, the quotation of "a kilometer" is commonly followed by no explanation, as being self-sufficient.

With so many of the civilized nations of the earth already wedded to the complete adoption of the metric system, and to the exclusion of their original primitive systems, it is only a question of time when free play of modern intercommunication will enforce the metric system here. It is generally agreed that the propagation-velocity of electromagnetic disturbances in free space is the same as that of light; that is, very nearly 3×10^5 km/sec. Since the length of a complete great circle of our globe, passing through the poles, is very nearly 4×10^4 km, this propagation velocity would carry an electromagnetic impulse 7.5 times around the globe in one second of time, or to the antipodes of any locality in 1/15 sec. Because of the effects of attenuation, and also probably to successive reflections between the earth's surface and the ionized layers in the upper atmosphere, the group velocity of radio-signalling waves, as thus far measured over long distances, seems to be appreciably less than the free propagation velocity, and is perhaps only about 2.5×10^5 km/sec.; but even so, the time of radio transit to the antipodes of any place is only about 0.08 sec., so that our planet has shrunk recently to 8 centiseconds of maximum separation by radio. The prospect of maintaining indefinitely more than one system of weights and measures on an 8-centisecond planet is surely very small? Will then the supervening single system be the 60-unit British system, the 50-unit American system, or the 3-unit metric system?

What is the Best System of Units for the Physical Sciences?

As we all know, physical science employs, in all countries, units of measurement that are based on the international *meter* and international *kilogram*. There are, however, various subsystems of these metric physical units, and there is room for international standardization in this respect. Most textbooks on physics are unitologically based upon the c.g.s. system, which was adopted in 1873 by the *Committee for the Selection and Nomenclature of Dynamical and Electrical Units* of the British Association for the Advancement of Science. As is well known, this classical c.g.s. system is single and unique, except in relation to electrics and magnetics, because it employs (1) an electric subsystem, based on the mechanical forces exerted between electric charges in free space, and (2) a magnetic subsystem, based on the mechanical forces exerted between magnetic poles in free space. Sometimes researches employ one of these two subsystems, and sometimes the other, so that a competent reader must be acquainted with both. Then there is (3) the Heaviside-Lorentz c.g.s. system, which is "rationalized," or has the constant 4π excluded from formulas dealing with rectilinear configurations, and inserted in formulas dealing with spherical configurations. It also simplifies many electric and magnetic working formulas. This system is much used by writers on theoretical physics. Theoretical physicists also employ (4) the Gaussian c.g.s. system, for which certain advantages may be claimed. Then there is (5) the universally employed series of "practical" international magnetic units—the *volt*, *ohm*, *ampere*, *coulomb*, *farad*, *henry*, *joule* and *watt*—all based upon the c.g.s. magnetic system, and connected with it by a corresponding series of decimal multiples (10^8, 10^9, 10^{-1}, 10^{-1}, 10^{-9}, 10^9, 10^7 and 10^7). International standards are constructed in this series, and all physicists conduct measurements in terms of them. Finally, because there are certain admitted small errors in the magnitudes of these international standards, with reference to the theoretical basic c.g.s. magnetic units, physicists recognize a slightly modified, or corrected, series, sometimes called the *absolute practical* series, in which there would be the "*true ohm*," the "*true volt*," etc. The exact magnitudes of these standards cannot, of course, be known; but as time goes on, and the precision of measurements improves, the numerical correction factors become more definitely recognized. Thus, at the present time, the Bureau of Standards' estimates of these correc-

tion factors, for the particular cases of the volt, ohm, ampere and watt, are:[5]

International volt	= 1.00043	true volts,
International ohm	= 1.00052	true ohms,
International ampere	= 0.99991	true ampere,
International watt	= 1.00034	true watts,

and so on for other international units. Some claim that these absolute practical units thus form part of another, a sixth system, with which well-informed physicists have in these days to be familiar. That is a question for debate; but at least these correction factors form a series which cannot be ignored by physicists when electrical measurements of the highest precision are made in the laboratory.

These five or six systems of scientific units, to say nothing of the gravitational systems, with the *foot-pound*, and *kilogram-meter*, lay an undue burden on teachers and students of physics. In addition, physicists in America lay an extra burden on their coworkers in non-English speaking countries when they introduce units from the vernacular into their scientific papers. In the interests of clearness and simplicity, a concerted effort should be made to work towards an international single and comprehensive system of units and the relinquishment of all the others. Such a possible universal system was proposed by the Italian physicist Giorgi in 1901. This system has been endorsed by leading unitologists in a number of countries, and does not seem to have raised serious objections in any, unless the departure of unit density from the density of water is so interpreted.

The Giorgi Proposed Comprehensive System of Practical and Physical Units

The Giorgi system adopts and includes the eight units in the practical series (*volt*, *ohm*, *ampere*, etc.) and builds this series into a completely comprehensive system by adopting the international *meter* as the unit of length, the international *kilogram* as the unit of mass, and the international mean solar *second* as the unit of time. These conditions satisfy the *joule* and *watt;* because the *vis viva* (Mv^2) of 1 kg, moving with a speed of 1 m/sec., is just 1 j. Except that unit density would be 1 kg/m^3, which is 10^{-3} g/cm^3, every important physical unit seems to fit into the system fairly well. A table of specific gravities would, of course, be the same in the Giorgi system as in the c.g.s. system. All electrical measurements and standards would remain as they are now; but the units of gradient, area and volume, such as *volts per meter*, *amperes per square meter* and *joules per cubic meter*, would be decimally altered from their counterparts in the c.g.s. system. There would cease to be a duality as regards electric and magnetic units, all units being in the present practical magnetic series; that is, there would be no separate set of electric units. Although there would be no necessity to abandon the c.g.s. systems if the Giorgi system were completed and internationally adopted, yet it would probably happen that the c.g.s. systems would gradually go into desuetude. Before that could come about, however, the magnitudes of a large number of physical units now applied in the c.g.s. system would have to be decimally altered, and tables of such units correspondingly modified, all of which would require time and mutual consent. If and when, however, such a system became generally adopted, the need for learning any other system of units than the Giorgi system should disappear in commerce as well as in science. This is an ultimate goal so earnestly to be desired that the merits of the Giorgi system should be carefully studied by all students of science and world affairs.

Dellinger-Bennett-Karapetoff-Mie System

There is one other proposed comprehensive system of units which may claim to be considered as an alternative for the Giorgi system. It was suggested by several different writers independently and has been referred to by some persons as the c.g.s.s., or *centimeter-gram-seven-second*, system. It proposes to adopt and include all the existing practical units as constituent elements, like the Giorgi system, but to use the *centimeter* as the unit of length, the *gram-seven* (10^7 g or 10 metric tons) as the unit of mass, and the *mean solar second* as the unit of time. The *joule* and *watt* are complied with, since the *vis viva* of 10^7 g moving with a speed of 1 cm/sec. is 1 j. In other respects, the system would run parallel to the Giorgi system. The unit of area would be the *square centimeter* and that of volume would be the *cubic centimeter*. Physicists accustomed to the use of the c.g.s. system would probably find these units more convenient than the *square meter*

[5] E. C. Crittenden, *Present Status of the International Electrical Units*, Trans. A. I. E. E. (1927), p. 990.

TABLE I. *Fundamental c.g.s. units and three derived "practical" systems.*

Quantity	Symbol	Fundamental c.g.s.	← Practical →					
			q.e.s. Maxwell (1881)	In c.g.s. Units	m.k.s. Giorgi (1901)	In c.g.s. Units	c.g.s.s. Dellinger-Bennett	In c.g.s. Units
Mechanic								
Length	L	*cm*	quadrant	10^9	*meter*	10^2	*cm*	1
Mass	M	*g*	eleventh-g	10^{-11}	*kilogram*	10^3	g-seven	10^7
Time	T	*second*	second	1	*second*	1	*second*	1
Area	S	*cm²*	sq. quad.	10^{18}	*m²*	10^4	*cm²*	1
Volume	V	*cm³*	cubic quad.	10^{27}	*m³*	10^6	*cm³*	1
Density	d or ρ	*g/cm³*	eleventh g/quad.³	10^{-38}	*kg/m³*	10^{-3}	g-seven/*cm³*	10^7
Velocity	v	*cm/sec.*	quad./sec.	10^9	*m/sec.*	10^2	*cm/sec.*	1
Acceleration	a	*cm/sec.²*	quad./sec.²	10^9	*m/sec.²*	10^2	*cm/sec.²*	1
Force	F	*dyne*	centidyne	10^{-2}	dyne-five	10^5	dyne-seven	10^7
Pressure	p	*dyne/sq. cm*	cntdyne/sq. quad.	10^{-20}	dyne-5/sq. *m*	10	dyne-7/sq. cm.	10^7
Torque	Q	*dyne⊥cm*	cntdyne⊥quad.	10^7	dyne-5⊥*m*	10^7	dyne-7⊥cm	10^7
Moment of inertia	J	*g-cm²*	11th-g-quad.²	10^7	*kg-m²*	10^7	*g-cm²*	1
Energetic								
Work	W	*erg*	*joule*	10^7	*joule*	10^7	*joule*	10^7
Power	P	*erg/sec.*	*watt*	10^7	*watt*	10^7	*watt*	10^7
Thermal								
Heat	H	*g-calory*	11th-g-cal.	10^{-11}	*kg-calory*	10^3	*g-calory*	1
Temperature	t or T	*deg. C. or abs.*	*deg. C. or abs.*	1	*deg. C. or abs.*	1	*deg. C. or abs.*	1
Luminous								
Flux	F	*lumen*	*lumen*	1	*lumen*	1	*lumen*	1
Illumination	E	*phot*	lumen/quad.²	10^{-18}	*lux*, lumen/m²	10^{-4}	*phot*	1
Intensity	I	*int. candle*	*int. candle*	1	*int. candle*	1	*int. candle*	1
Brightness	B	candles/cm²	candles/quad.²	10^{-18}	candles/m²	10^{-4}	candles/cm²	1
Focal power		cm⁻¹	quad.⁻¹	10^{-9}	*diopter*	10^{-2}	cm⁻¹	1
Electric								
Electromotive force	E	abvolt	*volt*	10^8	*volt*	10^8	*volt*	10^8
El: field intensity	e or V	abvolt/cm	volt/quad.	10^{-1}	volt/m	10^{-2}	volt/cm	10^8
Resistance	R	abohm	*ohm*	10^9	*ohm*	10^9	*ohm*	10^9
Resistivity	ρ	abohm-cm	ohm-quad.	10^{18}	ohm-m	10^{11}	ohm-cm	10^9
Current	I	abampere	*ampere*	10^{-1}	*ampere*	10^{-1}	*ampere*	10^{-1}
Current density	i	abamp/cm²	mp./sq. quad.	10^{-19}	amp./sq. m	10^{-5}	amp./sq. cm	10^{-1}
Conductance	G	abmho	mho	10^{-9}	mho	10^{-9}	mho	10^{-9}
Conductivity	γ	abmho/cm	mho/quad.	10^{-18}	mho/m	10^{-11}	mho/cm	10^{-9}
El: quantity	Q	abcoulomb	*coulomb*	10^{-1}	*coulomb*	10^{-1}	*coulomb*	10^{-1}
El: displacement	D	abcoulomb/cm²	coulomb/quad.²	10^{-19}	coulomb/m²	10^{-5}	coulomb/cm²	10^{-1}
Capacitance	C	abfarad	*farad*	10^{-9}	*farad*	10^{-9}	*farad*	10^{-9}
Permittivity	κ_0	(abfarad/cm) = 1	farad/quad. =	$\frac{1}{4\pi v^2}$	farad/m =	$\frac{10^7}{4\pi v^2}$	farad/cm =	$\frac{10^9}{4\pi v^2}$
Frequency	f	cycle/sec.	cycle/sec.	1	cycle/sec.	1	cycle/sec.	1
Magnetic								
Magnetomotive force	$\mathcal{F}$	gilbert	*amp.-turn*	$\frac{4\pi}{10}$	*amp.-turn*	$\frac{4\pi}{10}$	*amp.-turn*	$\frac{4\pi}{10}$
Mag: field intensty	H	gilbert/cm	amp-turn/quad.	$4\pi/10^{10}$	amp-turn/m	$4\pi/10^3$	amp-turn/cm	$4\pi/10$
Space permeability	μ_0	abhenry/cm	henry/quad.	$1/4\pi$	henry/m	$10^7/4\pi$	henry/cm	$10^9/4\pi$
Magnetic flux	Φ	*maxwell*	volt-second	10^8	volt-second	10^8	volt-second	10^8
Mag. flux density	B	maxwell/cm²	volt-sec./quad.²	10^{-10}	volt-sec./m²	10^4	volt-sec./cm²	10^8
Permeance	$\mathcal{P}$		henry	$10^9/4\pi$	henry	$10^9/4\pi$	henry	$10^9/4\pi$
Reluctance	$\mathcal{R}$		yrneh	$4\pi/10^9$	yrneh	$4\pi/10^9$	yrneh	$4\pi/10^9$
Inductance	L	abhenry	*henry*	10^9	*henry*	10^9	*henry*	10^9
Magnetization	I		volt-sec./quad.²	$10^{-10}/4\pi$	volt-sec./m²	$10^4/4\pi$	volt-sec./cm²	$10^8/4\pi$
Magnetic pole	m	maxwell/4π	volt-sec.	$10^8/4\pi$	volt-sec.	$10^8/4\pi$	volt-sec.	$10^8/4\pi$
Chemical								
Electrochemical equivalent		*g*/abcoulomb	11th-*g*/coulomb	10^{10}	kg/coulomb	10^{-4}	g-seven/coulomb	10^{-8}

and *cubic meter* of the Giorgi system. On the other hand, the *centimeter* is not so desirable a fundamental unit of length as the *meter*, and 10^7 g is a very large and awkward size and name for a fundamental scientific unit of mass. In the opinion of the writer, the *meter* and *kilogram* are much more desirable as fundamental units than the *centimeter* and *gram-seven;* but because at least one textbook[6] has been published in the c.g.s.s. system of units, it seems only fair to present it for consideration along with the Giorgi system, in which apparently no books, but only individual papers, have thus far been printed.

One question would have to be decided before either the Giorgi or the c.g.s.s. system could be adopted internationally: namely, whether the unit of magnetomotive force should be the *ampere-turn* or the 4πth part of one *ampere-turn*. This raises the question of so-called "rationalization" and affects several other practical units, not thus far settled upon. If the unit of magnetomotive force were made the *ampere-turn*, the logical effect would be to identify the strength m of a magnetic pole with the amount of magnetic flux Φ emerging from it, and also the quantity q of an electric charge with the electric flux emerging from it, thus identifying electric flux and displacement. Various other simplifications would be effected.

[6] See Bibliography, No. 8.

Thus, the specific tractive force between opposed parallel pole-surfaces carrying uniform flux density B would be $B^2/2\mu_0$ instead of $B^2/8\pi\mu_0$, where μ_0 is the space permeability. Also, magnetic volume energy would be $B^2/2\mu$ instead of $B^2/8\pi\mu$, where μ is the permeability of the medium. Again, the hysteretic work, per unit of volume and per cycle, of a magnetic substance subjected to uniform cyclic magnetization would be equal to the area of the Ewing loop in HB units, instead of being $HB/4\pi$. In electrostatic formulas, like simplifications would occur.

Table I lists 45 quantities in the c.g.s. magnetic system, and also in the only three practical systems that present themselves for consideration (all here rationalized). The first is the q.e.s., or *quadrant-eleventh-gram-second*, system, discovered by Maxwell. The second is the m.k.s. system, and the third is the c.g.s.s. system. The *quadrant* (10^7 m) is so great a unit of length, that no one has seriously proposed the practical adoption of the q.e.s. system. In order, therefore, to complete the existing practical series of units into a complete practical system, choice seems to lie between the m.k.s. and c.g.s.s. systems. For general scientific work, it would seem that the m.k.s. system has the advantage. It would be a great misfortune if electrophysicists and electrotechnicians adopted a practical system that physicists and technicians in other branches of science found themselves unable to accept.

Bibliography

1. G. Giorgi, *Unità Razionali di Elettromagnetismo*, Atti dell'A.E.I. (1901), p. 402. 2. M. Ascoli, *Sul Sistema di Unità proposto dall'Ing. Giorgi'*, Soc. Ital. di Fisica (Sept., 1902). 3. G. Giorgi, *Proposals concerning Electrical and Physical Units*, Trans. Int. Elec. Congress of St. Louis 1, 136–141 (1904). 4. F. A. Wolff, *The So-Called International Electrical Units*, Trans. Int. Elec. Congress of St. Louis 1, 143–169 (1904). 5. J. H. Dellinger, *International System of Electric and Magnetic Units*, Bureau of Standards, Sci. Paper 292 (1916). 6. E. Bennett, *A Digest of Relations between the Electrical Units and of the Laws Underlying the Units*, Univ. of Wisconsin Bull. (Nov., 1917). 7. G. A. Campbell, *A System of Definitive Units Proposed for Universal Use*, Proc. Int. Math. Cong. of Toronto (1924); also Science **61**, 353–357 (1925). 8. Bennett & Crothers, *Introductory Electrodynamics for Engineers*, McGraw-Hill, New York (1926), p. 665. 9. A. E. Kennelly, *Historical Outline of the Electrical Units*, Proc. Soc. Prom. Eng. Educ. **19**, 229–275 (1928). 10. A. E. Kennelly, *Vestiges of Premetric Weights and Measures in Metric System Europe, 1926–1927*, Macmillan, New York (1928). 11. C. O. Mailloux, *La Question du Gauss*, Revue Gén. de l'Elect. Paris, **29**, (Jan. 24, 1931). 12. A. E. Kennelly, *Rationalised versus Unrationalised Practical Electromagnetic Units*, Proc. Am. Phil. Soc. **70**, 103–119, (1931). 13. Leigh Page, *Electromagnetic Equations and Systems of Units*, Physics, **2**, 289–302 (1932). 14. V. Karapetoff, *A General Theory of Systems of Electrical Units*, Trans. A.I.E.E. (Sept., 1932), p. 715. 15. A. E. Kennelly, *Recent Actions Taken by the Symbols, Units and Nomenclature Committee of the International Physical Union*, *Trans. A.I.E.E.*, *Winter Convention*, New York (Jan., 1933).

HUMAN happiness depends chiefly upon having some object to pursue, and upon the vigor with which our faculties are exerted in the pursuit.—JOSEPH PRIESTLEY, in the preface to *History of Electricity.*

IT is commonly said that P. G. Tait laid down the length of a drive on mathematical principles which could not be exceeded, and that his son drove the ball farther. But at that time Tait had not realized the full effect of spin on the ball.—SIR OLIVER LODGE, in *Past Years, An Autobiography.* Young Tait was a golf champion.